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REVIEW OF FIBROUS DUST PROBLEMS AND RESEARCH REQUIREMENTS IN MINING

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SUMMARY

The inhalation of asbestos minerals has led to serious health problems in numerous individuals engaged in mining and processing. Some individuals not involved with the asbestos industries have also suffered disease from secondary exposure. Long thin fibers are considerd most injurious to health. However, lung biopsies reveal dominantly sub micron fibres, and these may well be a serious cause of disease.

It appears likely that most fibres which have dimensions below 10 μm in length and which are durable in body fluids have a carcinogenic potential, either in their own right or due to the surface absorption of carcinogens due to the fibres' surface charge.

Substitutes for asbestos fibre, both natural and man made, should be assumed dangerous until specifically shown to be otherwise through animal and cell culture studies.

Analysis of a representative sampling of Atlantic Canada mines has shown a lack of fibrous components in that portion of the respirable range which is optically visible. Some, however, have host rocks which have been subjected to temperature and pressure conditions which can lead to the developement of minerals which are known to have a fibrous morphology. Optical methods of identification of asbestos minerals, such as dispersion staining, can be incorporated with the phase contrast system to effect identification of a specific asbestos mineral during routine counting.

Summary of Recommendations for Research

1. The solubility of fibrous minerals in biological fluids as a function of exposed surface area should be documented. This is essential for the interpretation of medical study results pertaining to the relative carcinogenicity of different fibrous mineral species.
2. The surface charge per unit area of mineral fibres for all species should be catalogued and correlated with solubility data in body fluids.
3. Medical studies should be undertaken to determine the effectiveness of the human system in rendering inert, fibres of various types and size distribution.
4. A study should be initiated to determine the degree to which organic molecules suspected of being carcinogenic might be adsorbed onto the charged surface of asbestos fibres during their journey from initial milling through various manufacturing processes.
5. The ability of submicron plate like minerals to penetrate through cell membranes should be investigated.
6. Rock wool fibres produced from various rock types should be analysed to determine the relationship of the expected devitrification products to the parent materials. It is possible that rock materials containing amphibole minerals should be avoided for this purpose.

Recommendations for Research

7. The consistency of the size distribution of the fibrous component, if it exists, of aerosols from various locations within a mining system should be measured. This would enable an estimate of dose of sub-micron fibres. At present, no data is recorded concerning the dose received of fibres less than 5 μm in length.
8. For regulation purposes it is desirable that the counting system be capable of distinguishing among various fibres that may be present. Research should be undertaken to effect this capability.
9. Research should be initiated into the development of membrane filters of a specific refracture index for fibre monitoring purposes. Specifically, a filter of index 1,550 would satisfy the requirements of the chrysotile industry in Canada.
10. Since fibres implicated in mesothelioma are dominently less than 0.5 μm in dimension, all mine atmospheres in Canada should be sampled and analysed using the electron microscope.
11. Research should be undertaken to develop a counting system for asbestos dust monitoring which is able to identify the fibres being counted.

INTRODUCTION

1.0 It is today readily apparent that inhalation of the asbestos minerals has led to serious health problems in numerous individuals, dominantly among but not exclusive to, those individuals who are involved in the mining and processing of such fibres. Asbestosis is an irreversible disease characterized by diffuse fibrosis of the lungs with accompanying functional changes such as reduced vital capacity, obstructed bronchial passages and restricted expansions of the lungs. There are secondary effects of respiratory exposure to asbestos in high levels such as plural frictional rubbing, rales, cyanosis (low blood oxygen content), clubbing of the fingers and the formation of asbestos warts. Cancer of the larynx and bronchus also have a higher incidence amongst asbestos workers that it does the general population. The development of mesothelioma, a tumor involving membranes such as the pleura, pericardium and peritoneum, is attributed dominantly to asbestos exposure, and in some cases to very low asbestos exposure.

Numerous cases have surfaced throughout the world of "asbestos related diseases" amongst peoples whose contact with an asbestos operation was minimal or non existent. Examination after death reveals the presence of asbestos fibres in the lung tissue of virtually all such cases reported. Indeed, it appears that asbestos and other mineral fibres can be found in the lung tissue of most of the population of the industrialized world. Some sources of mineral fibres have been traced to soils in farming areas but most is produced by mining, processing and the use of asbestos.

Because of the low exposure involved in some who have developed asbestosis and asbestos related cancers, and because other mineral fibres have been shown to cause similar biological effects in animal studies, low level exposure to any fibrous mineral is now recognized as potentially hazardous.

The asbestos minerals are lttle more abundant in nature than many other fibrous minerals. They do, however, occur in sufficient concentration to form ore. Other minerals such as sillimanite, wollastonite, the zeolite minerals, brucite and other fibrous clay minerals are generally secondary in nature and occur in minor amounts disseminated throughout mineral deposits and indeed, all geological formations.

In the mining and processing of ores from Canadian mines, it is highly probable that some fibrous minerals are present in the dusts produced in such operations. Whether they exist in concentrations sufficient to cause fibre related disease, or in a size range large enough to be in the respirable range is largely unknown. Also, the effect of concentrations of dust below the limit of resolution of the microscope is largly unknown.

1.1 The purpose of this study was threefold:

(a) To determine from the literature the properties or fibre which are implicated in the induction of disease.

(b) To examine the methods used to collect and analyse fibrous minerals with a view to determining their adequacy.

(c) To determine the extent to which fibres may present a problem in Atlantic Canada mine atmospheres.

This was accomplished by an extensive examination of the literature and by an analysis of dust samples collected from more than 90% of the mines of Atlantic Canada. It was felt that if a fibre problem existed in Canada, the mines from Newfoundland through New Brunswick were diverse enough to be representative of the rest of the country.

1.2 DEFINITIONS

Biological Activity - "possessing chemical, physical and steric properties that allow reaction with receptor sites in living systems at the host, organ, tissue, cell and macromolecule levels".

Respirable dust - a dust of such size that it may be deposited in the non-ciliated portion of the respiratory tract when inhaled.

Asbestosis - a diffuse pulmonary intersticial fibrosis, caused by inhalation of respirable fibres with or without accompanying reaction of the visceral and/or parietal pleura.

Exposure can lead to development of the following abnormalities in other organs

(1) Skin corns

(2) Asbestos bodies in lungs and sputum

(3) Interstitial pulmonary fibrosis: asbestos

(4) Pleural hyaline and calcified ploques

(5) Bronchogenic carcinoma associated with asbestos

(6) Malignant mesothelioma of pleura and perifoneum

(7) Gastrointestional carcinoma

Asbestos - is a general term for a number of naturally occuring fibrous mineral silicates. They crystallize in narrow veins as bundles of minute fibres, easily broken into individual fibrils upon disturbance. They have perfect lengthwise cleavage and a high length to width ratio. All of the asbestos minerals also occur in non-fibrous form.

The asbestos minerals and their corresponding nonasbestiform varieties are:

Chrystotile	Lizardite and antigorite
Fibrous tremolite	Nonfibrous tremolite
Fibrous actinolite	Nonfibrous actinolite
Fibrous anthrophyllite	Nonfibrous anthrophllite
Amosite	Cummingtonite and grunerite
Crocidolite	Riebeckite

Fibre - For industrial control purposes a fibre is defined as a particle whose length is a least three times greater than its diameter. (There are non-fibrous minerals whose tabular form meet this criteria. However, within a mine producing a specific asbestos mineral, it is realistic as mechanical refining processes can break the fibres).

Mesothelioma - Malignant mesothelioma is a tumor that arises from the tissue lining of the chest (pleural) or abdominal (peritoneal) cavities. It grows to ensheath and constrict the internal organs, interferring with their function.

FIBRE DUST STUDY

SECTION 2

Physical and Structural Properties of Fibrous Minerals and their Relationship to Carcinogenesis

2.0 Physical and Chemical Properties of Fibrous Minerals and Their Relationship to Carcinogenesis

2.1 Brief History

The unique properties of asbestos have been known and appreciated for centuries. It was first described by Plutarch who introduced the name αοβεστα, meaning indestructible. One of its earliest uses was in the wicks of lamps and was reported to be used in the perpetual lamps of the vestal virgins. It was described in the first century AD by Plutarch as "soft, petrous, filamentous yarn made into towels, nets and womens head coverings which cannot be burned by fire, but if any become soiled by use their owners throw them into a blazing fire and take them out bright and clean..." There are stories of Charles V amusing his guests by throwing tablecloths into a fire from which they emerged whiter than when they went in. In Finland, the use of asbestos to pack crevices in log huts had been used from time immemorial. Asbestos has also been used in Finland, dating back to 2500 BC, pottery containing asbestos fibres having been found.

Due to its unique chemical and physical properties its use has grown in this century and a great impetus to its application was given by the discovery of large deposits in Canada.

2.2 Structure of Asbestos and Asbestiform Minerals

Asbestos is a generic team and refers to several forms of hydrated silicate rocks, each varying from the other in composition and crystal structure. The National Bureau of Standards at a workshop on Asbestos "Definitions and Measurement Methods" defined asbestos in 1978 as "a

collective minerological term which includes the asbestiform varieties of various silicate minerals". The term asbestiform refers to a special fibrous habit of the mineral with properties that are distinct from other crystal habits of the same mineral.

The Occupational Safety and Health Administration (OSHA) defines asbestos from the point of view of health risk. The naturally occurring minerals chrysotile, amosite, crocidolite, anthrophyllite, tremolite and actinolite are classified as asbestos if the individual fragments are: longer than 5 micrometers, maximum diameter less than 3 micrometers and an aspect ratio ≥ 3. For monitoring purposes, any of these minerals in the stated size range are classified as asbestos. This presents obvious problems for the mineralogist since non asbestiform minerals can form ascircular crystals and clevage fragments which satisfy the size criteria. At the same time it excludes minerals of silicate and other groups whose structure is clearly fibrous.

There are two main asbestos forming minerals groups. The amphiboles and the serpentines. In both, the basis structural unit is the tetrahedral silica group SiO_4.

The difference between these two groups is a reflection of the manner in which the silicate anions $(SiO_4)^{-4}$ are bonded to each other through shared oxygen atoms.

In the amphibole group the SiO_4 tetrahedrons are joined by sharing one oxygen atom and the resulting chains forming double chains also by

the sharing of oxygen atoms. The basic repeat unit is the $(Si_4O_{11})^{-6}$ anion. Figure 2-1.

Silicate minerals contain metal ions such as Mg^{++}, Fe^{++}, Ca^{++}, and (OH) groups. In the amphiboles these ions are incorporated between the double chains providing the electrostatic field holding the chains together. The five amphibole asbestos minerals all have this double chain structure, the basic unit containing two Si_4O_{11} units (or Si_8O_{22}) as can be readily recognized from their formula

Amosite $(Mg, Fe^{2+})_7\ Si_8\ O_{22}\ (OH)_2$

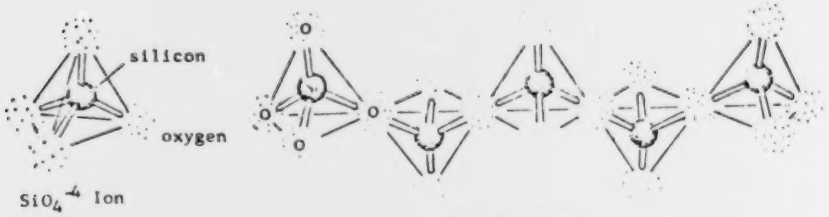
Anthrophyllite $(Mg, Fe)_7\ Si_8\ O_{22}\ (OH)_2$

Crocidolite $Na_2\ (Mg, Fe^{2+})_3\ Fe^{3+}_2\ Si_8\ O_{22}\ (OH)_2$

Tremolite $Ca_2\ (Mg, Fe)_5\ Si_8\ O_{22}\ (OH)_2$

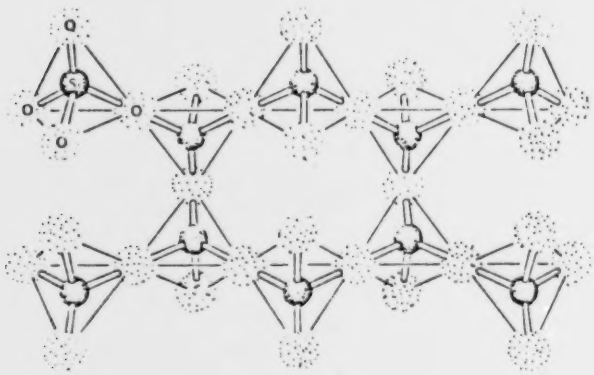
Actinolite $Ca_2\ (Mg, Fe)_5\ Si_8\ O_{22}\ (OH)_2$

All these amphiboles contain iron and magnesium. The chains of these minerals, which are four tetrahedra wide, run parallel to the asbestos fibre axis, providing the mineral with its dominant asbestiform characteristic. Tremolite and actinolite form a continuous series, its name depending on the Fe/mg ratio. Neither of these two minerals is of economic importance. There are many other double chain silicate minerals that do not form into fibrals but exist in a different habit. In addition to the asbestos minerals there are many other silicates and other mineral types that form fibres but are not in sufficient quantity to be commercial. Commonly, such minerals are found widespread in metasomatic and metamorphosed rocks as an accessory mineral and can be associated with the fine material released in the grinding process while mining other mineral deposits. For example,

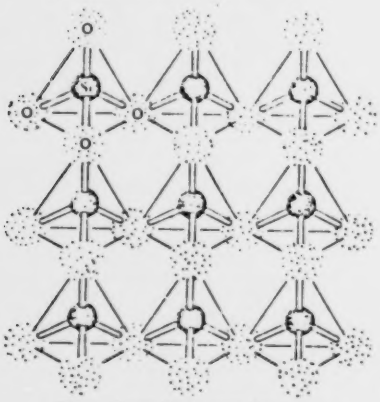


SiO_4^{-4} Ion

Single Chain



Double Chain Amphibole



Silicate Layer (Serpentine Minerals)

figure 2.1

wollastonite, $CaSiO_3$, unrelated to the pyroxine group but with a somewhat similar chain structure, form in impure limestones, a host rock for many of our commercial mineral deposits. The general reaction is $CaCO_3 + SiO_2 = CaSiO_3 + CO_2$.

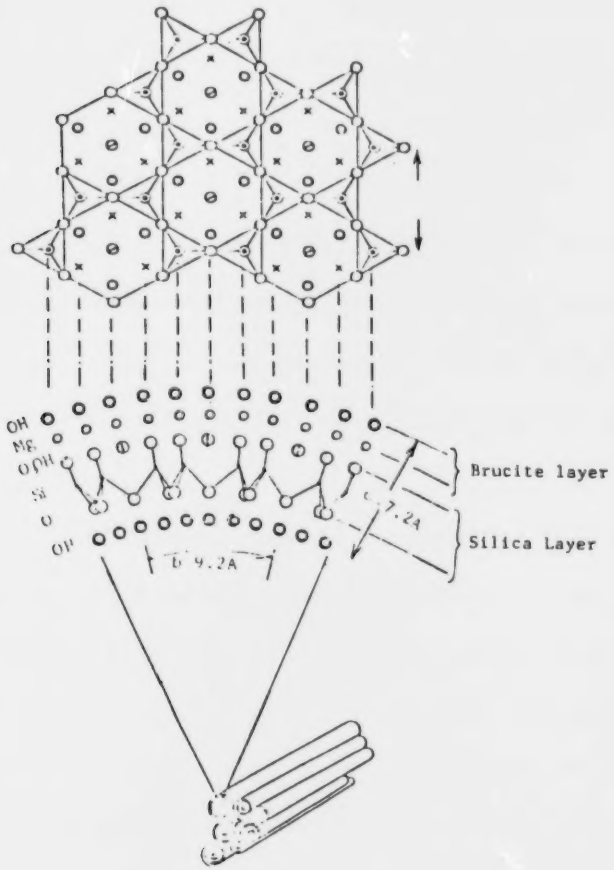
Brucite, $Mg(OH)_2$ is a layered silicate structure, and is similar to the outer layer of the mineral chrysotite. It has a fibrous variety, nemalite, which can occur as an alteration of periclase (MgO) in contact metamorphosed dolomites, and as a low temperature hydrothermal vein mineral in serpentinites and chlorite schists.

The mineral sericite, a finely divided muscovite mica, when subjected to high grade metamorphism is commonly dissociated to form potassium feldspar and sillimanite (Al_2SiO_5), commonly in the fibrous form fibrolite.

Chrysotile also has a basic structure composed of SiO_4 groups but these are arranged in sheets. The silicate chains can be considered to be extended into a layer by further sharing of another oxygen atom of the SiO_4 unit. The basis repeating unit is now (Si_2O_4). Three of the four oxygen atoms in the SiO_4 group are shared. Attached to this sheet are magnesium hydroxide octahedra. (Brucite layer)

The plan and elevation view of the idealized structure of a serpentine fibre is shown in Figure 2-2.

Due to the difference in spacing between opposite sides of the unit cell the sheet is stressed and curves to form a scroll. The diameter of the individual tubes are of the order of 25 mm and the length to diameter ratio can vary from 5 to 10,000. This feature of being able to separate into long fibrils or tubes only a few tens of



Structure of a chrysotile asbestos fibre.

figure 2.2

nonometres in diameter is common to all six of the "asbestos" minerals.

2.3 Other Fibrous Silicates

Although chrysotile is the only commercially valued asbestiform layered silica, there are many layered silicates known to occur in a similar habit. Some are rare but others are comparable to chrysolite in relative quantity, disseminated throughout ignious and metamorphic rocks. Fibrous talc $3MgO.4SiO_2.H_2O$ has long been recognized and given such names a beaconite and agilite. Tubular Holloysite $(Al_4\ (OH)_8\ Si_4\ O_{10}.\ 4H_2O$, a kaolin like clay mineral and fibrous attapulgite (polygorskite) $(Mg, Al).(OH)_2\ Si_4O_{10},\ 4H_2O$, are strikingly similar to asbestos. The mica Pyrophillite $(Al_2(OH)_2\ SiO_4)$, Muscovite $(KAl_2(OH)_2\ Si_3$ Lepidolite $K\ Li_2\ Al(OH)_2\ Si_4\ O_{10}$ and gloveonite display good asbestiform fibres. Mullilte $(2SiO_2.3Al_2O_3)$ and anatase (T_1O_2) occur as rods which fulfill the currently accepted definition of a fibre.

All of the chain silicates have good prismatic cleavage: Their crystals will break along planes parallel with the tetrahedral chains. There are many minerals whose basic structure is a chain silicate. The following list of minerals are all chain structure silicates and all are different in the basic configuration of the chain:

Single Chain	Triple Chain	Complex Chain
Iscarite	Sillimonite	Astrophyllite
Pyroxene	Amphibole	Sapphireine

Single Chain	Triple Chain	Complex Chain
Wallastonite	Elpidite	Stillwellite
Batiste	Xonolite	Howieite
Pentagonie		Vlosovite
Rhodonite		Narsarukite
Stokesite		
Pyroxmangite		

Less than 1% by volume of all amphiboles crystallize in the asbestiform habit and some make commerically valuable deposits. That the other chain silicates have not crystallized into commercial asbestiform deposits is no reason to assume that they do not attain fibrous forms.

The subgroup of the zeolite minerals (natrolite, edingtonite, thomsonite and others with general compositon (Na, Ca, Ba) $(Si, Al)_5 O_{10} \cdot n H_2O$) usually crystallize in a fibrous habit. Whether these are considered asbestiform or not, they are durable in biological environments, their tubular form is not dissimilar to chrysotile and they have a silica tetradedral frame. Are they as harmful as asbestos? To answer this we really need to know the properties of asbestos that initiate the physiological damage leading to carcinogenesis.

That the recognized asbestos mineral can, when inhaled, induce pleural changes leading to mesothelioma and other cancers of the lung, has been recognized and accepted for some years. The controversy still rages, however, as to why and how this occurs. At one extreme are those who insist asbestos is a carcinogen and would replace it by man made fibres having most, if not all, of the technically desirable

features of the mineral, its morphology, strength, durability etc. At the other end are those who would ban the use of any naturally occuring mineral having fibrous properties occuring in any concentration in the respirable range. Since the accepted regulatory definition of a 3 to 1 aspect ratio for asbestos minerals (serpentines and amphiboles) allows some tabular and acicular amphiboles to be considered and counted as fibres, many of our minerals will have fibrous dust components by definition.

2.4 Physical Properties

It is becoming increasingly evident from the literature that it is some of the properties of asbestos and not necessarily asbestos itself which leads to cancer. Those implicated can be put into three categories.

(1) Those properties which enable minerals or man made substances to penetrate and remain deep into the lung alveoli and to penetrate the cell, i.e., those properties which give biological access.

(2) Those properties which enable the dust particle to survive in a hostile body environment, such as low solubility in physiological fluids.

(3) Surface properties of the dust which enable cell-particle interaction, especially those which interfere with the basic biochemistry of the cell, such as surface charge.

For each of these categories we list the following properties:

Category 1 - Biological Access

(a) Size, limited to the respirable range

(b) Shape - diameter if a fibre and minimum dimension if a plate. (One enters by puncture, the other by slicing.)

(c) Rigidity or flexibility

(d) Density and surface area, affecting generated stress at contact points.

Category 2 - Durability

(a) Specific surface

(b) Solubility

(c) Absorption properties

(d) Density

Category 3 - Biological Activity

(a) Chemical Composition

(b) Surface charge distribution

(c) Specific surface

(d) Absorption properties

2.5 Properties Leading to Biological Access

There are two families of characteristics of mineral fibres which are important in the etiology and pathogenesis of tissue change. These are characteristics which lead directly to clinical disease or characteristics which enhance the biological availability of that mineral. In the former case, chemical composition would be expected to be of prime importance. In the latter, characteristics such as shape, charge distribution, specific surface area, solubility in body fluids etc., would be expected to dominate. Biological activity will be defined as in a paper by P. Kotin (1977) as "possessing chemical, physical, and steric properties that allow reaction with receptor sites

in living system at the host, organ, tissue, cell and macromolecule levels". A particle of spherical form and a fibre may be composed of similar atoms and both be potentially carcinogenic. The fibres, however, may have access biologically whereas the particle may not. In general, when two of the three dimensions of a particle are small relative to the third, biological access is maximized as in the fibre. When all dimensions are large or small relatively, biological acceess is minimized. An intermediate case is when one dimension is relatively small. Thus plate minerals such as the micas, should have biological access intermediate to the tabular and fibrous species.

2.5.a. Fibre Length and Diameter. These are necessarily related as the aerodynamic diameter is a function of both. Fibres having a given diameter will behave aerodynamically in the same manner as spherical particles of the same density that have a significantly larger diameter. The equivalent aerodynamic diameter of a fibre (de) is given by the expression $de = 66d\ [\frac{B}{2+4B}]^{2\cdot2}$. Where d - actual diameter and B = aspect ratio. (Gross 1981). The aerodynamic equivalent diameter of fibres in the respirable range is roughly three to four times its actual diameter for aspect ratio greater than 40, up to lengths of 150 μm. Assuming that a unit density sphere larger than 3.5 μm has little chance of reaching the alveolor sacs, then a fibre 1.5 μm or more in diameter and 10 μm or more in length has little chance of alveolor deposition. The alveolor deposition of fibres 0.5 μm actual diameter drops rapidly with increasing length from about 16% at 25 μm long to 3% for 120 μm. For fibre 1.0 μm actual diameter, deposition drops from 14% for 10 μm long fibres to 2% for 100 μm long fibres.

Thinner fibres may have increasing deposition rates as length increases to 40 μm and fall off again as length increases. (Gross 1981)

Within the alveolor region of the lung the dominant deposition mechanisms are impaction for particles longer than 1.5 μm aerodynamic diameter, sedimentation for 0.5 to 1.5 μm diameter particles. (Lippmann 1980). Total respiratory track deposition for normals reaches a minimum of 10-20% for particles between 0.2 and 1 μm. The major factor determining the probability of depostion of the smaller particles is their transfer from tidal to reserve air and they may remain airborne for several breaths before actually depositing. Under these conditions, a long thin fibre of similar aerodynamic diameter to a shorter longer diameter one is more able to contact the alveolor wall and deposits more readily. This effect would be true also of platy particles but would be less pronounced than for fibres.

In a paper by Stanton [1977] experiments using various asbestos minerals, within the same size range, show equal carcinogenic effect. The size range for maximum effect was a diameter <0.25 μm and a length >8 μm. Within this range, fibres were uncompromised by phagaocytic activity and lay free in the intersticial tissues of the lung. The statistics relating size distribution with tumor probability show a correlation with fibre size up to a diameter of 2.5 μm.

Clearance of fibre from the alveolor region of the lung is dominantly by macrophage engulfment and transport up the trachia on the mucoclia transport system. Fibres longer than 8 μm appear to be incompletely phagocytosed by the macrophage and lead to cell leakage and fibrosis [Hardy, C.J., 1978. Wright and Kuschner, 1975). Fine

respirable fibres of greater lengths can penetrate both cell and nucleus membrane and cause non-lethal damage. Non-lethal alteration of the cell nucleus is perhaps the most direct event that could initiate cancer. It might also be expected that the probability of such cancer initiation upon cell nucleus membrane penetration would be related to the surface properties of the penetrating fibre.

2.5.b. Surface Area and Charge

There is a strong interaction between all of the asbestos minerals and the membrane of the red blood cell. This haemolytic activity in chrysolite is attributed to its positive surface charge caused by the outer layer of magnesium hydroxide ions (bructie layer). All of the asbestos minerals possess a surface charge, as do clevage fragments of all non conducting minerals. It has been observed that air borne fibres in the milling operation have a greater tendancy to flocculate than do those at the manufacturing stage. This can be explained by the unsatisfied surface charge as the fibres are separated. As processing continues such charge imbalance may become satisfied by adsorption of organic molecules, many of which could be carcinogenic. This might also occur within the lung of asbestos minors and millers where the sinergistic effect of smoking is most significant. Morgan et al (1977) in investigating the haemolytic activity of various amphibole fibres, both natural and artificial, demonstrated this activity is related primarily to specific surface area. The correlation between haemolytic activity and specific surface give a correlation coefficient $r = 0.92$. This suggests that the smaller the fibre diameter the greater the haemolytic activity since more surface area is available per unit mass

dose. This effect should decrease as the fibre length becomes less than the 7 μm diameter of the erythrocyte. This is in agreement with the observation that fibres from the mines of New Cape area of South Africa, having smaller diameters than that of crociodolite fibres mined in the Transvaal, also exhibit greater haemolytic activity. The haemolytic activity of amphibole asbestos and crystolite is due to the interaction with protein in the erythrocyte membrane.

There appears to be a correlation between in vitro haemolytic activity and in vivo fibrogenicity. It appears possible that all fibrous minerals are fibrogenic and that the longer thinner fibres are the most so. The ability of asbestos dust to lyse erythrocytes was found to be decreased by coating with a surfactant or by leaching. This correlates with a decrease in surface charge on the fibres. An hypothesis involving transfer of electrons of DNA to asbestos has been proposed to account for the genetic effects of the dust. (W.G. Light and E.T. Lai, 1980).

In a paper by Stanton et al 1977, seventeen fibrous glasses of diverse type and dimensional distribution were implanted in Osborne-Mendel rats. Neoplasmic response correlated well with fibre dimensions. Fibres less than or equal to 1.5 μm diameter and greater than 8 μm in length yielded the highest probability of pleural sarcomas and it was suggested from probability trends, pleural sarcoma incidents increased with increasing length of fibres with diameters less than 1.5 μm. Since neoplasmic response to a variety of types of durable fibres were similar, the experiments reinforced the idea that carcinogenicity of fibres depends on dimension and durability rather than physochemical

properties and emphasizes that all respirable fibres be viewed with caution.

2.5.c. Chemical Contaminants

It has been suggested that the chemical nature of asbestos fibres or contamination substances such as oils or heavy metals is responsible for the carcinogenic effects of this mineral. If such is the case, asbestos ground to a size range which eliminates its fibrous nature should still be carcinogenic since the chemical nature has been preserved.

Experiments performed by Stanton (1977) eloquently eliminate chemical composition. It was found that the carcinogenicity of all asbestos is greatly reduced when ground to very submicroscopic fibrils or pulverized to non-fibrous particles; that contaminating carcinogenic metals and hydrocarbons, when attached to inert non-fibrous particles of a size comparable to asbestos, do not show the carcinogenicity of asbestos. It was also found that all asbestos types, within the same size range, have equal carcinogenicity and that this is so with or without heavy metal contamination.

2.5.d. Solubility of Fibres

Cohort studies of asbestos workers have suggested that some asbestos fibres are more carcinogenic than others. If this is so it would appear to be due to greater accessibility of some fibres to the cell biology and longer retention time.

It has been suggested by a number of investigators that chrystotile dissolves more readily in the body than do other asbestos fibres. In a paper by G. Oberdorster et al (1980) the solution rate of

most of the trace element in chrystotile are also confirmed to be several times faster than in either amosite or crociodlite in cold HLC. Magnesium is almost completely leached from crystotile in hydrochloric acid solution.

2.6 Other Fibrous Minerals Implicated in Carcinogenesis

2.6.a Stanton and Wrench (1972) have reported experiments in which glass fibre was introduced into the pleural cavity of rats by surgical techniques. These studies indicate that glass fibres of diameter (0.06-3μm) were capable of producing mesothelial tumors.

Clearance of particles and fibres from the lung occurs mainly by way of the trachia. Macrophages which have engulged the material are moved up the trachia on the mucociliary transport system. Research by C. Hardy (1978) and others show also a considerable involvement of the lymphatic system in clearance of fibre particulates from the lungs. In experiments with glass fibres, evidence of their entry into the lymphatic system is given by their appearance in the lymph nodes. Long microfibres when phogocytosed by macrophages can cause leakage of cell contents and release of destructive enzymes, and the long fibres are more capable than short ones of producing fibrosis in the lung.

The activity of a fibre in the lung is also influenced by its retention time. This is influenced by such factors as solubility, surface distribution of charges and the manner in which its shape affects the clearance efficiency from the lung.

FIBRE DUST STUDY

SECTION 3

Biological Effects of Exposure to Fibre

3.0 Biological Effects of Exposure to Fibre

Introduction

3.1 Exposure of man to airborne clouds of mineral dust is known to be associated with subsequent development of various lung diseases. The type of disease which develops appears to depend on the mineral types present in the aerosol and their morphology.

Exposure to both silica and asbestos can lead to the development of a fibrotic disease called either silicosis or asbestosis. In the case of asbestos exposure however, exposure may also lead to bronchogenic carcinoma or mesothelioma.

Exposure of animals have shown similar patterns, following introduction by inhalation introtrocheal instillation, intrapleural innoculation or implantation. However, experiments using the nonfibrous polymorphs of asbestos fail to produce carcinoma of the lung, or mesothelioma but glass fibres introduced into the pleural cavity can produce such effects.

It appears likely then that the common mineral characteristics leading to cancer related disease are those which impart an ability to penetrate into intimate contact with the biological material of the cell and influence its chemistry. These characteristics are small size fibrous habit, and surface charge distribution.

3.2 Clearance of Dust from the Lung

Macrophages and giant cells engulf fibres in the lower lung and move toward the periphery of the lung by pleural drift, carrying dust particles through alveolar wells. Some macrophages accumulate near large bronchioles and may carry asbestos fibres through the bronchiolar wall and into the lumen where the fibres will be released. The intracellular dust removed from alveoli will escape the body via sputum. (P.F. Holt, 1982) After first exposure to dust, asbestos bodies first appear in the sputum about 3 weeks after exposure. Since the number of asbestos fibres that are phagocytized depends on the number of macrophages available, dust can remain extracellular for long periods if there are few macrophages. Asbestos bodies have been found in sputum 20 years after heavy exposure to asbestos has ceased. It has been suggested (Nizze, 1981), that after massive doses of asbestos dust the supply of macrophages may be exhausted allowing free dust particles to remain in the alveoli.

In the lungs of many patients, asbestos bodies are difficult to find and yet one study (Whitwell et al 1977) found greater than 100,000 uncoated fibres per gram of dried tissue in 88% of all mesothelioma patients examined. This suggests a lack of macrophage cells in these patients.

There are many references in the literature to the effect that short exposure to asbestos fibres at any time during life leads to a significant increase in cancer risk in later years. This has been referred to as the time bomb of residence asbestos exposure. (Seidman et al, 1977)

Depending on the diameter of the fibre within the aerosol, depositional intensity will vary in locations withn the respiratory system.

Fibres > 5 μm in diameter seldom get past the nose.

Fibres > 3 < 5 μm enter the trachia but do not penetrate the lung.

Fibres > 1 < 3 μm reach the smaller bronchi.

Fibres < 1 μm deposit in peripheral airways and air spaces through brownian movement.

Length is not an important factor as far as penetration into the lungs is concerned. Nearly all fibres found in the lungs of animal or man are < 3 μm in diameter and < 20 μm in length. Fibres > 3.5 μm diameter and fibres shorter than 5 μm appear to be handled by the body in the same manner that non fibrous particles are handled and are removed or denied biological access. Fibres in the submicron range may, if they enter the nonciliated regions beyond the bronchioli, and especially if the dose is massive, penetrate the air sac walls. One study on the examination of lung tissue found that only 12-30 percent of the fibres examined were optically visible. (Heppleston, 1979).

Experiments (Morgan and Allison, 1980), exposing the peritonial and alveolar macrophages of test animals (guinea pig, mouse, rabbit) to minerals (silica, chrysotile) show a release of lysosomal enzymes and tissue damage. This is especially true when the fibre length exceeds the macrophoge diameter. The initial activities of mineral fibres (chrysotile, crocidolite) correlates with the number of long/thin fibres. (Brown et al, 1980). The degree of leaching (dependent on the mineral species and on its residence time in the tissue) is also a

factor in its biological activity. The relationship between biological activity and degree of solubility is shown in Figure 3-1.

Solubility effect appears to follow the model:

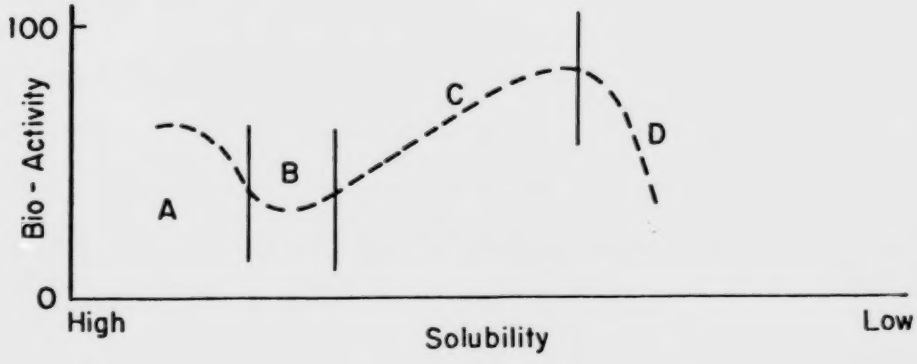


Figure 3-1

Zone A - can be highly toxic as the mineral constituents rapidly enter the blood stream.

Zone B - particles are dissolved slowly but are eliminated before enough time passes to allow them prolonged entry into sensitive areas.

Zone C - Particle half life is long compared to time required for extensive tissue reaction.

Zone D - mineral fibres of very low solubility can have high or low biological activity depending on their surface area and surface charge distribution and intensity. A fibre such as chrysotile with a positive surface charge should increase in biological activity as its diameter decreases (increasing surface area relative to mass). There will however be a diameter below which its capacity to effect biological damage decreases. Below this diameter, it has insufficient residence time before completely dissolving and this offsets the increased biological activity due to increasing surface area.

A number of papers have been written concerning the half life of fibres and particles both inhaled into the lung and inplanted into experimental animals. Some compare the half lives of different minerals, without stating the relative surface area distributions. Such comparisons are of minimal use.

Leaching decreased the toxic action of chrysotile (J. LaFuma et al, 1980) and the latent period before tumor occurrence increased with the degree of leaching. Such leaching would reduce the positive surface charge imparted by the brucite layer and minimize the fibres capacity to interact with cell chemistry.

In a report by Timbrell (1980), fibre from lung tissue was presented on a length vs diameter plot. The upper boundary for the adult plots was a line, diameter^2 length = 100. For a child $d^2 \ell$=300. This in effect says a child is capable of accepting fibres into the lung tissue three times as massive as those that can be accepted by an adult. The largest fibre diameters found in an adult was 2.7 μm while in a child it was 3.8 μm. Using the above relationship for an adult, a 2 μm diameter fibre was respirable if shorter than 25 μm. While a one μm diameter respirable fibre could be 100 μm long.

3.3 Effect of Fibres on Cell Biology

Light, W.G., and Wei, E.T., (1980) proposed an hypothesis involving transfer of electrons from DNA to asbestos to account for the genetic effects of the dust. All durable (non-soluble) particles which acquire a substantial and persistent charge on their surface can take part in electronic interactions with crucial macromolecules and would be potentially toxic.

The surface charge (as represented in terms of Zeta potential) of asbestos and glass fibres can be greatly decreased by a surfactant absorbed on the fibre surface (W.G. Light and E.T. Wei, 1980, E.S. Flowers, 1980). It can also be changed by leaching (M.C. Jourond et al, 1980) which frequently occurs in the body. Unleached chrysotile (+44.5mv) decreases in absolute value when leached whereas crocidolite (-43.5mv) increases in absolute value.) (W.G. Light, E.J. Wei, 1980) (74). A highly significant correlation ($p < 0.01$) between Z and haemolytic activity (H) was realized, H increasing rapidly with an increase in the absolute magnitude of Z.

Fibre solubility is important not because the material dissolved from the fibre is toxic but because of the effect dissolution has on surface charge. Fibre dimensions are important in determining whether fibres are able to reach sites where critical cellular interactions take place and thus could govern whether the potential biological activity of fibres due to their surface charge is displayed.

In a paper by Earl S. Flowers on detoxification of fibres, it was shown that the toxicity of fibres was reduced significantly by removing soluble mg ions and masking silicate binding sites with ferruginous material. (1980).

T.M.C. Davis (1979) agrees with long fibre theory (> 20 μm). However, chrysotile tends to break down lengthwise, producing thinner fibres. That chrysotile was far more carcinogenic than amphibole asbestos possibly is due to thinner fibres.

The important determinants for the biological activity and therefore the disease producing potential of fibres are the dimensions

of fibres, the dose, and the durability (solubility and strength) (J.P. Leineweber, 1981).

The release of enzymes from the mouse peritoneal macrophages exposed to amphibole asbestos, man made mineral fibres and non silicate mineral fibres was found with all materials. The release of enzymes from the cells appears to correlate with the fibrogenicity of the minerals in vivo. (Davies, R., 1980).

There appears to be a difference in the risk of lung cancer between different groups of workers. The observed/expected ratio ranges from 1.2:1 in chrysotile miners and millers to 17:1 to insulation and textile workers (Anderson et al., 1976). One would expect the size distribution to go to smaller mean diameters as one does more work on the mineral, from mining to the final utilization stages. This leads to fibres remaining airborne longer and inhaled, and allowing deeper penetration into the lung. Becklake and co authors have shown that various pulmonary symptoms and abnormalities are more common in workers in a factory manufacturing insulation and textiles than in those of a mine where the measurements available suggest that conditions are dustier. A further possibility as to the increased cancer risk among those in the asbestos "use' industries over mining and milling is that during milling, the fibrilation process produces fibres, the surface charges of which have not yet attracted carcinogenic molecules from the atmosphere. By the time the fibre reaches the secondary processing and manufacturing stage, many such molecules could be firmly attached, ready to be transported into the body. Also carcinogens from cigarette smoke may transfer to the fibres within the lungs during smoking.

Mesothelioma in the general population has been reported from Turkey, in association with a mineral deposit containing fibrous zeolite used for building purposes. (Elmes, P.C., 1980)

Experiments by Wright and Kuschner (Wright, G.W. and Kuschner, M. 1975) in which glass fibres of various length had been introduced into the lungs of guinea pigs by intratracheal installation suggest that fibres with 92% > 10 μm in length produce a fibrotic lesion whereas short fibres with 93% < 10 μm in length produced only macrophage aggregation. It appears the fibrogenic effects of long glass fibres are related to the incomplete phagocytosis of such fibres by macrophages in the lung which results in leakage of tissue damaging enzymes.

Mesothelioma is a rare disease and the majority of cases occur in association with exposure to fibrous minerals, dominantly asbestos. The latent period is from 20 to 55 years for this tumor. A number of cases however have been reported in the literature of mesothelioma in children. (Wassermann, et al, 1980) It has been suggested that exposure to asbestos may have occured during fetal life. This possibility has been demonstrated with animal experiments (Pontefract, R.D. and Cunningham, H.M., 1973)

A study by Smith and Hubert (1980) on 60 hampsters used insulation grade glass fibers injected into the right pleural space at 25 mg./animal. The results showed 9 tumors, the earliest after 284 days using 0.10 μm diameter fibers with 82% larger than 20 μm. For thicker fibres (0.33 μm) with 46% greater than 20 μm in length and 1.23 μm diameter with 34% longer than 20 μm) tumors were found in two, the

earliest after 408 and 533 days respectively. For diameters of 0.09, 0.41 and 1.49 μm but with < 2% of the fibers greater than 10 μm, no tumors were found.

Previous investigations by the same researchers using glass fibers with mean diameters of 5 μm injected intrapleurally failed to produce any tumors.

Due to lattice discontinuities and impurities, as a fibre is reduced in diameter, its length also has a tendency to be cleaved. Aerosols with fibers less than 0.1 μm diameter mean size can be expected to have relatively few fibers greater than 10 μm in length.

Malignant tumors have been induced in rodents by injection of a wide varity of minerals of low solubility (and hence the potential for a long biological half life). (Bischoff, F. and Bryson, G.) This leads one to speculate on the significance of injection experiments using mineral fibers. Negative results may reflect non carcinogenicity while positive results may prove nothing pertinent to the fibrous nature of the mineral.

Clearance of particles from the alveolar region of the lung depends on their transport to the terminal bronchioles by alveolar macrophages. Particles to enter and be detained in the alveolar region efficiently must have an aerodynamic diameter between 2 and 10 μm a size range which can be effectively engulfed by a microphage. Fibers can however be considerably longer than 10 μm and still be within the effective aerodynamic diameter for respiration and entrapment within the alveolar region. Mobilization by macrophage will be difficult if not impossible in such long fibre sizes.

A study by Morgan (1980) showed that short fibers are cleared from rat lungs more efficiently than are longer ones. Length measurements of fibers from lung biopsies of three workers exposed during the second world war to amphibole fibers and who developed mesothelial tumors since 1963 show a mean length of 20 μm. It was stated that in general, long asbestos fibers are absent from the lungs of people who have not been exposed to asbestos occupationally. A further observation was that thicker fibers are more easily coated than thinner ones and it is the long thin uncoated fibers which are responsible for the pathiological effects.

The smaller the diameter of a fibre becomes, the greater is the ratio of surface area to mass. The mass rate of solution is therefore greater and the particle may cease to exist more quickly by solution. Many of the aluminum silicate minerals remain very insoluble in the small size range. A study by J. Bignan et al (62) shows attapulgite fibre, a clay mineral, at a concentration of 300,000 fibres/ml in the urine of a 60 year old woman treated for six months with a drug containing this mineral. The mean length was 0.93 μm and the average aspect ratio 20:1. These fibres passed through the gastrointestinal mucosa and had access to organs not directly in contact with the external environment.

Exposures to high concentrations of talc dust in mining and processing in the U.S.A. has been shown to cause pulmonary fibrosis and a four fold increase in the incidence of malignant tumors of the lung or pleura (Kleinfeld et. al. 1967). Such effects may have been due to amphibole asbestos minerals associated with the talc. In Great

Britain, Henderson et. al. (1975) described talc particles in association with carcinoma of the ovary and cervix. It has been shown by the McCrone Institute that talc can form very tiny cleavage fragments which have fibrous morphology.

3.4 Biological Effects of Fibres

(a) Fibrous Glass

The commercial term, "glass fibres" covers a wide range of mineral composition. For example, alkali resistant glass fibres designed for reinforcement of cement are based on 50% SiO_2 and 18% CaO in Great Britain. Similar fibres in the U.S. produced by Corning Glass are based on 85% basalt and 15% zirconia. In Germany phosphorous slog is the principal component modified with 1-10% zinc, chromium or titanian oxides.

Uses

Thermal and acoustical insulation, reinformcement of cement and various other materials. Commercial production is of diameters > 20 μm and are therefore non-respirable. Fibres of diameter < 10 μm diameter are made for special purposes, i.e., space shuttle, and may soon become available commercially.

Effects

Long fibres of glass cause localized damage to the cell membrance while being phagocytosed, similar to asbestos. (Beck E.G. 1980) The fibres also induce the formation of multi-nucleated giant cells through fusion. Fibres of length greater than 8 μm and diameter < 0.25 um show a strong correlation with tumor probability (R. Bertrand and H. Pezerat, 1980, Stanton et. al. 1977).

(b) Attapulgite - A clay mineral commonly found in fibrous form, the fibre bundles generally dispersing to a size range below the detection limit of the light microscope. Aspect ratio is of the order of 4 - 150. (Bignon. J. et. al. 1980).

uses: Oil and grease absorbant, pet absorbant bedding, pesticides, oil drill mud, account for 70% of the 1.2 million tons produced annually. The pharmaceutical industry uses 60 tons annually.

effects: Few studies have been published on this mineral. Gignon refers to a study by Patt et. al. 1976 where introperitoneal injection induced mesotheliomas in 24 of 34 rats. (Lockey J. and Brooks, S.M., 1960)

Haemolytic activity of attapulgite was equal to or greater than that of chrysotile according to Bignon. Two points made to explain the biological effects of the fibre were: the possibility of ionic replacement, due to unsaturated bonds at the top of the si-Al structural unit, and the specific surface (200-300 m^2/g) which is larger than chrysotile.

(c) Rock Wool

Rock wool is manufactured from somewhat impure natural raw materials. Any silicate rock can be used for its manufacture. A

molten stream of the material is subjected to air jets which impart the fibrous nature to the material. The fibre length is generally a few centimeters and diameter usually greater then 4 μm. This however is a function of the blowing process. Some crystalline structure from the original material usually exists and often leads to a devitrification of the fibrous mass with time. The fibrous elements decrease in length more so than in diameter.

Recent developments in space technology have led to the prodcution of sub-micron glass filiments for re-entry heat protection application. In general however, the bulk of the materials produced for commercial insulation purposes are non respirable when first manufactured. Crystallization with time however can produce angular and acicular cleavage fragments with low solubility and high surface change. Such fragments have increased potential for cell penetration and biological activity.

A study by Ciaccia, A. et. al. (1978) found large numbers of birefrigent particles of various shapes and dimensions present in areas affected by interstitial fibrous and within macrophages, amongst insulation workers exposed to rock wool insulation.

3.5 Recommendations for Research

1. The solubility of fibrous minerals in biological fluids as a function of exposed surface area should be documented. This is essential for the interpretation of medical study results pertaining to the relative carcinogenicity of different fibrous mineral species.
2. The surface charge per unit area of mineral fibres for all species should be catalogued and correlated with solubility data in body fluids.
3. Medical studies should be undertaken to determine the effectiveness of the human system in rendering inert, fibres of various types and size distribution.
4. A study should be initiated to determine the degree to which organic molecules suspected of being carcinogenic might be adsorbed onto the charged surface of asbestos fibres during their journey from initial milling through various manufacturing processes.
5. The ability of submicron plate like minerals to penetrate through cell membranes should be investigated.
6. Rock wool fibres produced from various rock types should be analysed to determine the relationship of the expected devitrification products to the parent materials. It is possible that rock materials containing amphibole minerals should be avoided for this purpose.

FIBRE DUST STUDY

SECTION 4

Monitoring and Measurement

Monitoring and Measurement

4.0 Dose Response Relationships

It may be that a level of exposure to fibre exists below which no risk of related sickness or death occurs. Such a level is termed the "threshold limit". Figure 4-1 shows possible relationships between dose and resonse.

Curve (c) has been assumed by most regulators in the past. It is realistic in the sense that exposure below a certain level is unlikely to affect one during a normal life span.

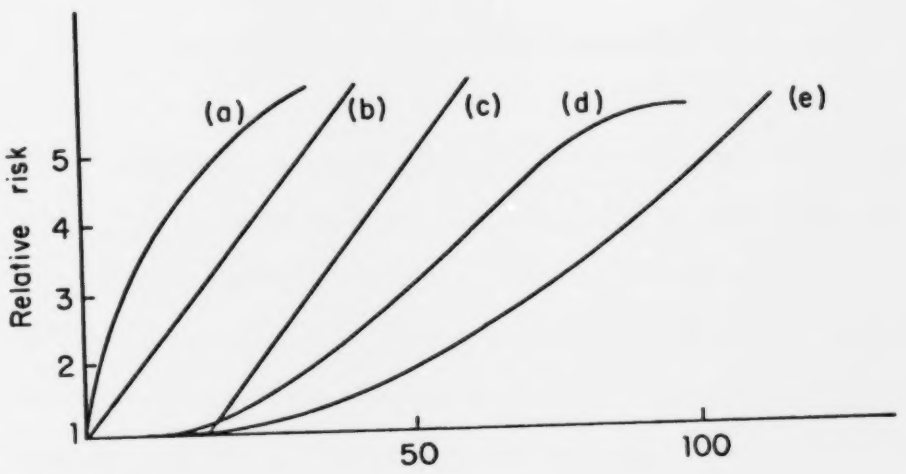


Figure 4-1

a - sublinear

b - linear

c - threshold

d - cumulative normal

e - quadratic

As man is subjected to an increasing number of environmental pollutants however, it appears that one of the other four representations is more realistic. Synergistic effects favour the quadratic dose response relationship of (e). Many studies show a linear relationship with no threshold limit adequately describe the data (Liddell et. al., 1977, Enterline et. al. 1972, seidman et. al., 1977).

The risk of pleural mesothelioma also increases with dose. McDonald's study of Quebec Chrysotile miners (McDonald et. al., 1980) showed the risk to be 10 times greater in heavily exposed workers than is those less heavily exposed. There appears to be no safe threshold for amphibole fibres in respect to pleural mesothelioma (Acheson E.D. et. al. 1980).

Becklake (1976) in a study of the prevalence of dyspnoea and of impairment of lung function in current mine and mill workers shows a relationship between all the parameters studied and increasing dose.

4.1 Submicron Fibre Concentration

The standards pertaining to the allowable concentration in an asbestos mining and milling complex allow 2 F/cc as a time weighted average, of fibres greater than 5 μm in length and less than five μm diameter with an aspect ratio of at least 3 to 1. Since the studies which have been used to set such a standard have not shown conclusively that smaller fibres are not implicated in asbestos related cancer, a problem of true dose versus measured dose arises. It has usually been

assumed that the number of small fibres not visible under light microscopy is proportional to the number of larger ones which are counted. This may be true for an individual plant producing asbestos but may not be true for other environments. In Figure 4-2 are shown three hypothetical dust distributions. Curve 1 happens to have a mean fibre size of 5 μm and 50% are < 5 μm. Distribution # 2 is more intense with the number of fibres of 5 μm length similar to that of distribution 1. However, the ratio of fibres < 5 um to those > 5 um is 3 to 1. In distribution 3 the ratio is 5:1. In distribution 4 the fibre count would be zero by accepted standard counting techniques whereas in reality there are more fibres in the distribution than in 1, 2, and 3 combined. For the aerosols represented by curves 1 to 3, the fibre count greater than 5 μm is very similar whereas the total fibre dose received is very different. Clearly then, the role played by the sub micron diameter asbestos particles must be more fully studied. Care must be taken in using standards developed for one industry in a different industry. For mining and milling, the mean fibre length falls above the limit of resolution of the accepted phase contrast counting method. For this case the numbers of small fibres will indeed be proportional to the numbers of large ones seen. For an industry where the mean size is below the resolution limit, as might well be in the grinding and fitting of clutches and brake linings, the number recorded from a membrane filter under phase contrast microscopy can grossly underestimate the fibre burden. The same would be true where find griding of an ore may liberate fibrous component, say of

wollastonite or brucite. Standard testing for fibre may not reveal the hazard in the worst case or underestimate it at best.

The counting problem has been further compounded by the lack of precision with which the term asbestos has been used. In many instances, non asbestos particulate fibres have been included in the asbestos count and later show to be synthetic or natural particulates from other plant sources, i.e. belting fibre, gasket material, cloth pipe joints, insulation etc.

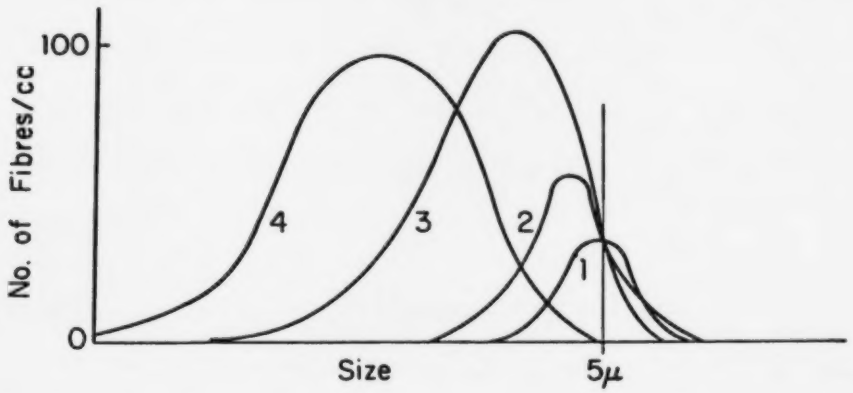


Figure 4-2

Aerosol distribution curves showing variation of total fibre dose relative to count greater than 5μm.

4.2 Methods of Analysis

Phase Contrast

The phase contrast microscope is a qualitative instrumental means of enhancing contrast. When studying particles one can choose the index of the mounting liquid to obtain a wide range in the degree of contrast and the phase contrast system is not necessary. The standard

NIOSH procedures for counting particles on a cellulose filter made transparent by treatment with diethyl oxalate and dimethyl phthalate fixes the indes of the media. Any fibrous mineral or other particulates whose index of refraction lies close to this value would have low contrast and could possibly escape detection and phase contrast enhancement is recommended.

The phase contrast principle was discovered in 1932 by the Dutch physicist, F. Zernike. It allows the phase difference in a specimen to be converted to an amplitude difference, yielding an image of good contrast.

The Particle Atlas, Vol. 1 of McCrone and Delly clearly explains this process. Light diffracted by a specimen is retarded relative to the undiffracted ray by $\lambda/4$. Neglecting the retardation upon passage through the specimen which is small for small particles, either the direct or diffracted ray is caused to pass through a phase plate retarding it a further $\lambda/4$. The total retardation is then $\lambda/2$. Under this condition, light passing directly through the specimen will destructively interfere with the diffracted rays producing an amplitude difference visible to the eye.

The use of phase contrast to count asbestos fibres has a further advantage. When diameters are less than 1 or 2 microns, the index of the particle relative to the medium can be readily ascertained. Using positive phase contrast, particles having an index lower than the medium will appear dark on a light field. For a particle of index higher than the medium, the particle appears lighter than the field. An experienced microscopist can use this to count only the chrysotile

asbestos content of a mixture of chrysotile and amosite for instance, or to recognize and discard non asbestos fibres from a count.

One of the reasons for the choosing of phase contrast by NIOSH and other regulatory agencies is the low level of training required for its use. As a result of this the system is much abused. Without Köhler illumination and accurate centering of the phase ring unsatisfactory results will be obtained. There is sufficient difference between the index of refraction of a cellulose collecting filter and most asbestos minerals that the use of phase contrast is unnecessary. Since phase contrast does not allow positive identification, a polarizing light microscope would be a much preferred system. The basic skills needed could be imparted in one week by such as the McCrone Research Institute, or any institute of higher learning where earth sciences are taught.

(b) Dispersion Staining

The dispersion staining particle identification technique is based on the difference between the dispersion of refractive index of the particle and the medium in which the particle is immersed. At the refractive index match point, the particle and medium would look as one, there being no contrast due to the absence of refraction of light traversing both particle and medium. Light of a wavelength above or below the matching wavelength will be diffracted. A system to observe the refracted components was developed to its current practical state by Walter C. McCrone of the McCrone Research Institute. The system consists of a central stop mounted in the back focal plane of a 16 mm objective lense. An axial beam of light from the condenser will have

its undiffracted components blocked out as they emerge from the objective lense. Diffracted wavelengths pass around the stop and are observable. The recombination of diffracted wavelengths produces a colour which is complimentary to that of the matching wavelength of particle and liquid. The device marketed by McCrone has a rotating turret containing several central as well as annular stops. The annular stop prevents transmission of the diffracted component to the eye so that the match point wavelength is observed directly. This is not as clearly observable to the eye as the colors of the darkfield central stop system due to the light background.

The mineral index which is matched is that index in the plane of the preparation parallel to the trace of the polarizer of the optical system used. For an axial beam, the plane of the preparation is perpendicular to the beam and the index of a specific crystal direction is determined. As the numerical aperature of the lense increases, as in higher magnification, a cone of light enters the preparation. The resulting colours observed now represent several index directions in the crystal with their diffracted rays superimposed. High magnification dispersion staining is therefore not diagnostic. It is however very useful for differentiating between small mixed particles of known composition and can be readily observed on the phase contrast microscope as currently designed.

The central stop dispersion staining system, when set up with Kohler illumination and carefully centered, is capable of detecting particles with a 16 mm objective to a size of 0.2 μm. This is below the theoretical resolution of the light microscope as it is usually

used. The reason is that the system does not ouline the morphology of the particle or distinguish between two points 0.2 μm apart. It allows observation of the degree of dispersion which occurs at the boundary of a particle in a specific liquid. This dispersion is observed as a color which is characteristic of the mineral species present and of its crystal orientation.

As a search mechanism, say to observe and count only the chrysotile fibre component of a mine atmosphere dust, the system is easily capable of detecting one fibre amongst millions of other fibres or particles and is also capable of giving positive identification. In chrysolile asbestos counting, the filter used would be required to have an index of refraction when rendered transparent, close to 1.550. A high dispersion cargille refractive index oil could then be applied rendering the filter transparent. Such a filter has never been requested and is not currently available.

For research purposes, of course, a sample can be observed under PLM as well as PC and the problem of including fibres other than the species under study seldom arises. For routine counting, however, it appears desirable to develop a system which better distinguishes one fibre type from another than does phase contrast. It is likely that a 400 x DS system, used in conjunction with a collection filter of the same refractive index as the fibre being counted, could be the basis of a diagnostic fibre counting system.

The midget impinger, extensively used throughout the mining industry for many years lends itself well to collection of aerosol dusts for observation under dispersion staining. A drop of liquid from

the instrument is allowed to go to dryness on a slide and the appropriate oil added.

The dispersion staining curves of many hundreds of minerals have now been published (McCrone 1979) and the required dispersion oils standardized by Cargille.

To produce sharp clearly visible dispersion staining colors, the particle and immersion liquid must have sharply interesting dispersion curves as shown in Figure 4-3

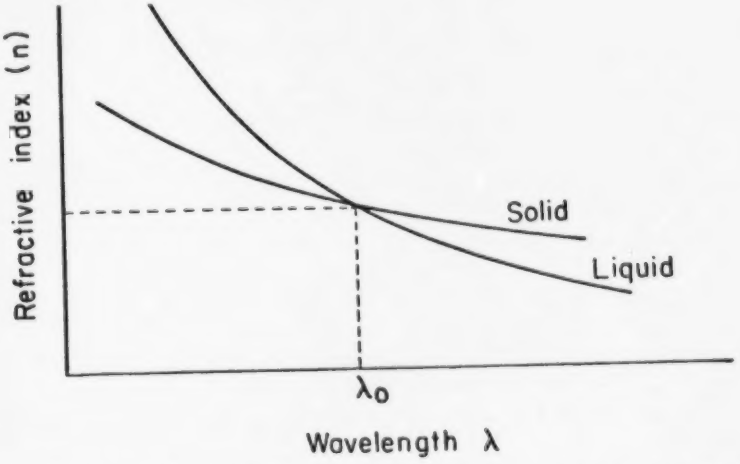


Figure 4-3 Dispersion Curves In Solid and Liquid (After McCrone)

A particle liquid system showing a match in refractive index for yellow light (λ_o = 589 nm) will show for the central stop, blue particles on a black field. With practice, the colors can be intrepreted to within 10 nm allowing very precise mesurement of refractive index in a specific crystal direction.

Dispersion staining curves, unlike the dispersion curves of figure 4-4, are plotted as $1/\lambda^2$ on the abscessa or wavelength scale and the difference of index between particle and liquid on the ordinate which gives nearly straight lines for the dispersion staining curves. Figure 4-4.

The dispersion of refractive index for a solid is usually less than for liquids in the same index range. A given solid will show different λ_o (different colors) in different liquids.

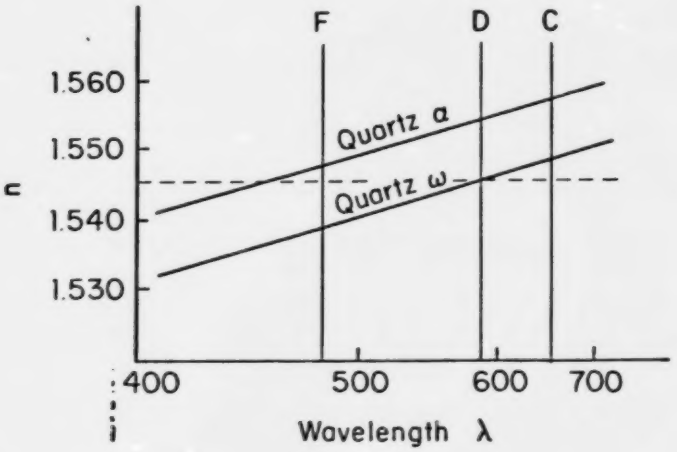


Figure 4-4 Dispersion staining curves, corresponding to the dispersion curves of Fig. 4-4.

(c) Transmission Electron Microscopy

The transmission electron microscope (TEM) has a resolution of about 0.2 nm. It is possible to observe a unit asbestos fibril and resolve its scrolled nature at 100,000 x. Identification can be achieved using selected area electron diffraction (SAED) which enables one to observe the electron diffraction pattern displayed by a single fibre. This pattern is characteristic of the mineral species crystalline structure. This process is rapid and available on most modern TEM machines, however it is expensive, and slow per sample since many fibres must be so examined. Not all chrysotile fibres yield SAED patterns on which identification can be based (Chatfield, 1978). Fibre counts for chrysotile are usually based on morphology, together with a

demonstration of a SAED pattern on a proportion of the fibres. For the amphibole fibres there is no characteristic morphology on which identification can be based. Identification is then on the SAED pattern only.

A further identification aid on the TEM, the energy dispersive x-ray analysis system (EDXA), detects x-ray emission from the electron irradiated fibre. It is possible to accumulate the entire x-ray pattern from a small particle in a few seconds. The peaks in the spectrum are characteristic of particular elements.

(d) Scanning Electron Microscopy

The scanning electron microscope (SEM) claims a resolution down to 5 mm and is thus also capable of measuring unit fibrils of asbestos minerals. The secondary electron mode usually employed in the SEM relies on topography for contrast. For smaller fibers, although there may be ample instrument resolution, the contrast may be insufficient to observe the particle against the background. Also the image observed by the operator is a persistence image, renewed usually twice a second. Surveying such images for widely separated fibrils among other debris is difficult. The SEM-EXDA technique can only be applied reliably to the analysis of particles > 1 μm.

There is also a scanning transmission electron microscope (STEM). An attachment to the TEM adds this capability. The resolution is about 3 mm and should improve to about 0.2 mm. It requires a thin electron transparent specimen as in the TEM but the image formation process is similar to that of the SEM.

Sampling of Mine Dust Atmospheres

4.3 There are a variety of techniques available to one to collect a representative sample of atmospheric dust from a mine atmosphere. One can in general either collect the sample, unfractionated, directly from the atmosphere; fractionate prior to removal from the air; or collect a sample which has naturally segregated from the atmosphere, either by sedimentation, impingement or natural thermal precipitation.

For purposes of indentification of specifically sought components within a mine dust, such as silica or a fibrous component, it is not necessary to size fractionate a sample during collection. All that is required is a representative sample so that the components sought, if they exist, will be included in the sample.

To determine the degree of hazard that a mineral component may present when present in a mine dust, one has first to sample for identification of the hazardous mineral and, if present, sample for concentration in the mine atmosphere.

Sampling for Identification Only

The smaller size fraction of a mine dust atmosphere will tend to precipitate onto the down stream vertical surfaces of metal structures very slowly over time. This fine dust adhering to the surface will provide a fairly representative time sample and can be collected either by placing a piece of transparent tape onto the surface and then onto a clean glass slide, or if the deposit is relatively thick, by brushing into a small sample bag. A similar sample, but extending into a larger size range can be obtained on horizontal surfaces where additional material collects through settling. Bulk samples can be collected in

this manner at various locations in the mine but two sites are probably adequate. One is adjacent to the primary crusher where the sample represents ore components over all grades. This is likely to be the most important since it represents the material in which the majority of mining activity, and hence dust generation, will occur. The second location would be in an area where excavation of waste rock in preparation for mining is being undertaken.

Bulk samples of this type can be used for XRD, TEM, SEM, and others in addition to polarizing light microscopy. In PLM, representative samples can be mounted on slides in media of any index required and individual particles, if mounted in a viscous medium (Aroclor 2442), rotated to any required orientation. If one is interested in particles of a certain diameter, say the respirable range of 5 to 10 um, the microscope itself is a size classification device. It is relatively easy to estimate the percentage of particles of a certain type which fall in a specific size range, making it unnecessary to use pre-sizing devices.

Once it has been established that a significant quantity of a hazardous mineral is present as a component constituent of the mine lithology, it is next necessary to determine if it is currently being liberated into the atmosphere and in what concentration. There are a number of general sampling methods available to determine this.

4.4 General Sampling Methods

There is much commercial equipment available for the separation of particulate matter from the air and removing it for analysis. In general, gross samples can be removed from the atmosphere by settling,

impinging or filtration. Settling is a simple system which usually consists of an open jar several inches across and deep enough to avoid disturbance by air currents. A liquid can be used to minimize re-entrainment once the particles are settled. The sample can be vacuum filtered through a membrane filter to isolate the dust.

Impingers

These simple devices were the standard dust collection system prior to the recommended use of membrane filters in 1975. The impinger can efficiently collect particles down to a size range of 1 μm. The midget impinger is very effective on concentrated aerosols as there is no sample buildup to increase resistance to air flow. The flow volumes for the impinger are generally 3 liters per minute and a typical sample collection time is ten minutes. Longer samples can be taken but this requires adding liquid to the impinger during operation to replace evaporation losses.

Impactors

Impactors utilize the inertial property of flowing particles, which tend to slip torward the outside of a curved path. The particles of greatest mass slip most, the smaller particles more closely following the gas flow. Size fractionation can therefore be effected by causing the larger particles to be impacted onto a surface and removed from the aerosal. The remainder smaller size fraction can be collected on a filter or impinger.

The Sartorius impactor is a commercially available single stage impactor which directs 2 to 5 ml of air per minute onto a glass disk at a speed of 1.3 m/sec. By disk rotation, 36 separate impaction sample

can be obtained. A microscope attached to the collector permits rapid sample examination.

The Cascade impactor consists of high velocity jets in series, each directing the air against a microscope slide collector at increasingly higher velocity, enabling each slide to collect particles of a small diameter. The particle size range on each slide is from 0.5 μm to 50 μm.

The Anderson particle size air sampler is a multistage multijet impactor, having several hundred jets in each stage which in turn has successively smaller jets. This was an attempt to simulate the respiratory tract in classifying airborne particles. An advantage over the single stage cascade impactor is a larger sample size.

The main disadvantage of collection by impaction when the impaction portion forms the sample is particle size reduction caused by the energy of impact. Also, the adhesive used to hold impacted particles makes subsequent handling and analysis more difficult.

Cyclones

Cyclones are inertial devices as are impactors but the design is such that the inlet aerosol stream is transformed into spiral flow. The particulate matter is forced to the outer periphery of the cyclone and slides to the bottom of the device. The rotating air mass moves back up the centre of the cyclone and discharges axially. The degree of particle separation is a function of velocity. A system of cyclones of decreasing size can be placed in series. In such a system, the increased velocity through successive cyclones leads to a smaller diameter particle being removed form the airstream. Samples are easily

removed from the system. This system has much to recommended it, especially if large samples are required. The sample size is simply a function of time.

Thermal Precipitators

Particles suspended in a thermal gradient will migrate toward the low temperature surface with small particles migrating most rapidly. This is due to the pressure increase of the heating air, exerting a force on the particle and displacing it toward the low temperature surface. Particles from 0.001 to 100 μm are collected with high efficiency.

Large temperature gradients of 400° C/mm, required for useful operation, can be achieved spacing a plate of 100 C, 250 μm from a water cooled collector plate.

Commercially available devices consist of an electrically heated wire, ribbon or plate parallel to a glass slide in contact with a heat sink, usually water. Typical sampling rates are 6 to 50 l/min.

Electrostatic Precipitators

As with the thermal precipators smaller particles are collected first and with the highest efficiency. Samplers consist usually of a fine wire extendng along the axis of a hollow cylinder. At a potential of 20 kv, ion discharge from ionized air molecules passing through the field attach temselves to dust particles which then experinece an attractive force toward the oppositely charged wall of the cylinder.

Qualitative and Quantitative Detection of Asbestos in Air Under Industrial Conditions

In ambient air, dust samples may contain but few asbestos fibres among much material of a different nature. Therefore, a high demand is placed on selectivity and sensitivity. In higher aerosol concentrations such as encountered during processing or manufacture, light microscopy is an attractive analytical tool. Since the refractive index of the fibre is close to the cellulose filter mounting media fibres can best be distinguished by phase contrast. Fibres down to a 0.5 um diameter can be detected. The relative accuracy of the count is ± 20%.

If the concentration of asbestos in the dust is higher still, >3%, it can be determined by physico chemical methods, i.e., X-ray defraction or infra red spectrophotometry.

X-ray diffraction is based on the phenomenon that the atoms that are vibrating around fixed points in the mineral act as centres of scatter. The diffraction pattern is characteristic of the mineral species while the intensity is a measure of the quantity of asbestos present.

Infrared spectroscopy is based on the phenomenon that the vibrating atoms in the mineral can absorb energy. Certain wave lengths of incident energy cause resonance and increased absorption of electromagnetic radiation. The absorption spectrum is characteristic and the extent of the absorption is a measure of the quantity of the asbestos present in the specimen. Asbestos content of the sample should be >1% and the sensitivity of determination is 10 μg.

Atomic absorption and emmission spectroscopy can be used only when the sample contains much asbestos.

4.5 The Membrane Filter Method

Membrane filters are porous polymeric films, available in pore sizes down to 0.01 μm. Their surfaces are smooth enough that penetration by particles is low. The filters can be dissolved onto a slide by a suitable solvent or it can be rendered transparent by treatment with an index liquid of the same refractive index. The filters add considerable resistance to the flow of air especially at the lower pore sizes.

The standard procedures prescribed by ACGIH for the sampling and counting of asbestos fibres specifies that the determination shall be made by the membrane filter method at 400x to 450x magnification and with phase contrast illumination. These filters must retain essentially all of the aerosol particles in excess of 0.5μm diameter. The background count should be less than 25 fibres over the whole surface of the filter, and the resistance should not exceed 3 mm Hg when filtering at a rate of 0.3 ℓpm per square centimeter. In sampling parctice, 2% to 4% of the filters intended for collecting samples should be set aside for background count determination.

When collecting the sample, the filter head is held downward which prevents dust from falling or being projected onto the filter. The flow rate is generally held at 2 ℓ/m by a constant volume flow pump when a 37 mm diameter filter is used. The time duration over which the sample is collected depends on the aerosol density. It is desirable that there be no more than 150 particles per field and less than 10

fibres per field. A recent unpublished study by Parsons & Bryant indicates that the variation is excessive when the number of fibres counted in total is less than 80.

Sample Preparation

As with the loading of the filters into their holders, a clean environment is required when mounting the filters in preparation for counting. A wedge of filter is placed onto a slide to which has been added an appropriate solvent. That recommended is a 50:50 mixture of dimethyl phthalate and diethyl oxylate in which has been dissolved 50 mg. of membrane filter per mℓ of solution to increase the viscosity. A word of caution on this medium - it has a pot life of less than 6 months due to the formation of crystals which grow in an asicular habit. In the early stages of formation when their numbers are low, the un trained eye could count these as fibres. The refractive index of this media is 1.461. The wedge of filter on the slide is covered by a coverslip and will clear in 15 minutes. Counts should be made within two days as the particles tend to migrate.

Counting

The equipment recommended by NIOSH is a phase contrast equipped microscope using 400-465x magnification and a 10x occular. As discussed in the section on phase contrast, the use of such a system is to change a phase difference to an amplitude difference when the indices of particle and mountant are close. The index of the recommended media for asbestos particle counting is 1.461, considerable below the indices for all asbestos minerals. It is doubtful whether phase contrast enhancement under these conditions is of any practical

use. The utilization of a polarizing microscope, especially one with a dispersion staining objective, would be much more effective in resolution and has the added feature of positive identification. Regardless of the microcope system used, it is essential that the Kohler method of illumination be used.

To effect the count, a Porton reticule is mounted in the eye piece which counts a field of 0.005 mm^2. It is recommended by NIOSH that one hundred of such fields be observed or 100 fibres counted, whichever occurs first.

In the identification and counting of unknown fibres in a dust which is essentially non fibrous, the membrane filter technique as recommended for fibrous dusts is satisfactory. However, a polarizing light microscope, rather than the phase contrast system, should be used. Once the presence of a fibrous component has been established and its intensity determined, it can be identified either by standard polarizing light microscopy techniques or by determination of its dispersion staining curves. A further advantage or PLM, especially when the fibrious dust component is low, is the ability to recognize contamination by man made or organic fibres which might otherwise have been included in the count using a phase contrast system.

Included in the definition by NIOSH of a fibre is that its length must be at least three limes its diameter. Although is is possible that a fragment of a fibrous mineral can have such a ratio, it is not common among the asbestos minerals. Particles with an aspect ratio less than 10 are more likely to be cleavage fragments of non fibrous minerals or possibly ascicular minerals. This is perhaps the most

important argument in favour of adopting a microscope technique for asbestos fibre counting which enables positive identification of the fibre and not merely observation of its shape as in phase contrast.

In mines whose production is other than asbestos, the standard for the determination of aerosol particulate content is based on the mass of particulate matter contained in a collected volume of air. The aerosol is first size selected so that only the respirable portion is removed. Such samples as currently collected can be used to ascertain the presence and quantity of fibrous minerals should they exist. For identification, particles merely have to be knocked off a portion of the specimen unto a glass slide and identified optically. Concentration determination is more difficult but can be accomplished. A representative portion of the filter can be dissolved and the particulate burden washed with an appropriate solvent, centrifuged and the clear liquid decanted. Several such treatments are usually sufficient to remove all traces of filter. Either a representative sample of the re-suspended particulates or the total sample can be mounted on a slide and counted.

4.6 Detection of Sub Microscopic Asbestos Fibres

The classic method to determine sub-microscopic particle concentration from a known volume of air is by precipitation on a substrate. The following techniques can be used.

(1) Filtration

(2) Electrostatic or thermal precipitation

(3) Centrifugation.

The particles are counted using an electron microscope.

The problems arising are centred around reproducibility and whether the counts are representative.

Since chrysotile divides easily into many fine fibres, the use of electroprecipatators where the dust is continuously washed from the electrodes, is not attractive.

4.7 Recommendations for Research

1. The consistency of the size distribution of the fibrous component, if it exists, of aerosols from various locations within a mining system should be measured. This would enable an estimate of dose of sub-micron fibres. At present, no data is recorded concerning the dose received of fibres less than 5 μm in length.
2. For regulation purposes it is desirable that the counting system be capable of distinguishing among various fibres that may be present. Research should be undertaken to effect this capability.
3. Research should be initiated into the development of membrane filters of a specific refracture index for fibre monitoring purposes. Specifically, a filter of index 1,550 would satisfy the requirements of the chrysotile industry in Canada.

SECTION V

Fibrous Dusts

in

Atlantic Canada Mines

5.0 Analysis of Dusts in Atlantic Canada Mines

To ascertain the degree to which fibres are present in the dust component of Atlantic Canada hard rock mines, the following sampling system was devised.

(1) A sample of the ore and host rocks of the mineral deposit was gently scraped onto series of slides, a cover slip added and index oils 1.550, 1.605 and 1.680 applied. A third sample was permanently mounted in Araclor 5442.

(2) A sample of dust, settled out over a period of years, was scraped from the vertical surfaces of steel structures adjacent to the primary crusher of the mine system. Such samples were similarly mounted as above.

(3) In some mines, aerosol samples were collected on open face filters using a duPont constant volume portable pump and cellulose membrane filter. This system of collection was unable to be used in most mines of Atlantic Canada since most were temporarily closed. Information from such collection was more adequately received from the scraping method of (2) above.

All samples collected were first observed by dispersion staining central stop at 100 x to search for the asbestos minerals chrysotile, amosite, tremolite, actinolite, anthrophyllite, crosidolite and cummingtonite. Other fibrous minerals whose refractive index was in the range of dispersion of the oils used would also have been observed during the process.

Having specifically searched for the above minerals, observation under polarized light was undertaken at 100x and 500x to further detect

any natural fibrous component in the preparations and to assist in identifying all mineral components. Also, as a further check on the presence of fibrous components, observation utilizing the standard phase contrast system at 500x and 1000x was undertaken.

Contamination of samples by paper fibres, fibreglass and the occasional asbestos fibre did occur but can be readily ascertained as being such.

Using the above search techniques, any of the asbestos minerals specifically sought for would likely have been detected down to a size of 0.3 μm diameter.

Other fibrous minerals outside the dispersion range of oils used would have been detected under polarizing light microscopy or phase contrast, down to a diameter of 0.5 μm.

The presence of fibrous components smaller than 0.3 μm diameter is a distinct possibility which was not investigated during this study.

The following mines were visited and sampled:

(1) New Brunswick Mining and Smelting.

(2) Heath Steele Mines.

(3) Consolidated Durham.

(4) Consolidated Rambler.

(5) Newfoundland Zinc.

(6) Newfoundland Minerals.

(7) Flintkote Gypsum Mines.

(8) Canada Wide Mines.

(9) Canadian Rock Salt.

(10) National Gypsum.

(11) Baroid (Buchans).

(12) Asarco (Buchans).

(13) I.O.C.C.

5.1 BRUNSWICK MINING AND SMELTING CORPORATION LTD.

Brunswick Mining and Smelting has one of the largest massive sulfide bodies in the world, with an estimated 25 years of ore in place. The ore is made up of small particles of lead, zinc, copper, silver and iron minerals, necessitating grinding to as small as 5 um. The processing has therefore the capacity to liberate any respirable fibrous minerals which might be present. This tendency to liberate respirable dust is minimized by utililizing a wet grinding process. However, the fines to tailings are a source of future respirable size particles liberated to the surrounding environment. The sulphide bodies of the Bathurst area are associated with a chlorite host rock and with quartz-feldspar-schists. Where iron formations have been mixed they are generally well laminated and grade into magnetite-chlorite schists. These in turn, in the current operation of Brunswick Mining, grade into massive sulphides. The chlorite schistose host rock is commonly highly sericitic. The presence of significant quantities of sericite (a finely divided muscovite mica) in an ore which is to be finely ground is important to note. In areas subjected to high grade metamorphism, this mineral is commonly dissociated to form potassium

feldspar and sillimanite (Al_2SiO_5). The latter commonly occurs in fibrous form (fibrolite) and can be released upon fine grinding.

The total work force at the complex as of January 1980, was 1600, and production was 3.3 million tons of ore.

Massive Specular hematite from the ore zone when scraped gently onto a slide contains dominantly specularite with varying amounts of magntitite, quartz, chlorite and in some specimen, some sphalerite. Particle size ranges from 0.9 μm to 40 μm. Some of the specularite cleavage fragments fulfill the requirements to be a fibre (3.1 aspect ratio) but are obviously irregular cleavage fragments.

Massive sulfide ore when gently scraped onto a microscope slide show dominantly sphalerite, hematite and chalcopyrite. Accessory minerals are quartz, calcite and some mica. Particle size varies from 2 to 200 μm. There are no fibrous components visible down to a resolution of 0.5 μm.

A sample of settled dust collected from a vertical steel surface near ore bypass 12 contains all the minerals mentioned above plus feldspar, and galena. The size ranges from 0.5 μm to 15 μm with the average being 6 μm. Some glass wool and fibreglass are present, presumable from some insulation process. A similar wall sample collected in the hoist room contains no fibrous material and has 5-10% quartz and sericite.

Of all the preparations examined, 21 slides in all, there were no detectible natural fibrous components in a size range grater than 0.5 μm diameter.

5.2 HEATH STEELE MINES

The geological setting is similar to that described for Consolidated Bathurst and the same potential for respirable fibrous sillimonite exists. The sulphide bodies are associated with a complex of interbanded chloritic tuff and quartz feldspar porphyry, the former being the host rock. At the current rate of production (400 tpd), life expectancy is 25 years.

Chlorite tuff - dominantly chlorite with 20% silica and vitreous glass. Size range from 0.5 μm to 20 μm. Flakes on edge can resemble fibres but no fibrous component is present.

Banded Lead-Zinc ore contains sphalerite and galena which easily forms sub-micron fragments.

Breccia ore when lightly scraped onto a slide shows chlorite and quartz fragment from the breccia, along with quartz, sphalerite and chalcopyrite.

Quartz parphyry produces a dust composed of fine silica grains, chlorite and altered feldspars. A specimen from the wall near the crusher contains particles from submicron size to 20°μm. Species present are sphalerite, hematite, magnitite, chalcopyrite, chlorite, quartz, feldspar, calcite and mica. No fibrous component is present.

5.3 CONSOLIDATED DURHAM MINES

The George Lake antimony mine is located 25 km north of Lake George, south west of Fredericton, N.B., and is owned by Consolidated Durham Mines and Resources Ltd.

The antimony ore in the Lake George mine occurs as lens shaped bodies irregularly distributed throughout the easterly trending Hibbard quartz vein system. Only minor amounts of antimony occur in the quartz veins. The main ore forming minerals are stibnite and native antimony. Other minerals in minor amount are bournonite ($2PbS\ Cu_2S\ SB_3S_3$), cholcostibnite ($Cu_2\ S\ Sb_2S_3$), plagionite ($5PbS\ 4Sb_2S_3$) and fuloppite ($3PbS\ 4\ Sb\ S$).

The main antimony ore zone is partially enveloped by a uranium bearing zone of hydrothermal origin. The main minerals in the mining zone are thucolite (Th-Ur Complex), uraninite and coffinite. Small amounts of soddyite $[(UO_2)\ 5\ (S_1O_4)\ 2(OH)\ 2.5H_2O)]$, and uranophane $(Ca(UO_2)\ 2\ (S_1O_3)_2\ (OH)_2\ 5H_2O]$ are also present. (Morrisey C.J., and Guitenbe A.A., 1980). The most abundant metallic gangue minerals are arsenopyrite, pyrite and pyrrhotite.

The quartz vein systems are emplaced in upper silurian greywackes and slates and the mine is within 5 km of several granitic intrusive bodies. Hydrothermal alteration effects are evident in the mine with the development of associated hydrothermal minerals, including fluorite. A micaceous and agrillaceous alteration halo envelopes the quartz-vein system, with its intensity increasing toward the vein.

Samples collected from surfaces near the crusher represent once air-borne dust over time. This settled aerosol contains 40 percent opaque ore minerals, the remainder being quartz and clay minerals. No fibrous minerals are present. Examination of the sedimentary host rock reveal clusters of sub-micron clay particles forming 80 percent of the

rock, the remainder being quartz. Mica flakes, when turned on edge are no longer resolvable, the plates being less than 0.3 μm thick. One fibre of brucite was detected by dispersion staining, having a length of 20 μm and a diameter of 1.5 μm. A search for further brucite fibres failed to find others in 8 separate preparations. Had one fibre in 10^5 particles been present of a diameter > 0.5 μm it would have been detected. This was likely contamination from some other source. The examination was conducted while at the McCrone Research Institute in Chicago.

5.4 CONSOLIDATED RAMBLER MINE

This operation is scheduled to close in late 1981. Up to 1979 it produced 1200 tonnes per day of chaleopynite ore and 750 tons/yr. in 1981. The total work form is currently 215 men.

The chaleopyrite ore, along with some gold and silver, occurs in zones along the contact between chlorite and sericite schists and on andesite tuff.

An airborne sample was collected underground near a drilling operation. The mean particle size in the aerosol was 0.8 μm with 90% being less than 3.6 μm. Particles were dominantly sericite mica with minor amounts of quartz. No particles had an aspect ratio greater than 2.

Analysis of a bulk sample collected near the primary crusher reveals particles of sericite, chlorite, quartz, sphalerite. The size ranges from 1 to 15 μm. No fibrous component was detected in a size range visible under the polarizing light microscope. The presence of

finely divided sericite leads to the possibility of sillimanite fibers and the sample should be further observed under the electron microscope.

5.5 NEWFOUNDLAND ZINC MINES (TECK AMAX)

The sphalerite mineralization occurs in irregular zones within a pseudo breccia of dolomite host rock. These pod shaped structures are generally small but numerous. The operation mines 0.5 million tons per year and employs 170 men.

Samples were collected from the steel structures adjacent to the primary crusher and a 0.8 μm pore size open face filters from the same zone. The bulk sample contains fragments of calcite, dolomite and minor sphalerite in a size range of 1 to 12 μm.

Analysis of the air borne specimen under PH 400x gives a size distribtion with a mean valve of 1.8 μm.

No fibrous component was present in any sample analysed.

5.6 NEWFOUNDLAND MINERALS

This is a hydrothermal alteration deposit containing high grade pyrophyllite, a layered aluminum silicate mineral not unlike talc. This is a small scale seasonal operation employing 12 men and is of sufficient quality that the ore is hand sorted as it enters the crusher via belt conveyor.

Samples were collected both from the vertical structures adjacent to the primary crusher and from the air using an open face membrane filter.

Analysis of settled particles reveal dominantly pyrophyllite in a size range from 0.5 μm to 12 μm averaging 4.4 μm. Particles are

generally irregular in outline and platy with an ossicular component. The irregular outline of this component, coupled with non undulatory extension suggest cleavage fragments rather than fibres.

Analysis of the air born sample collected by membrane filter and analysed under PH 450 x, shows a concentration of assicular fragments of 1.8 F/cc, comprising 2.5% of the sample. There are no fragments with an aspect ratio > 10:1.

5.7 FLINTKOTE GYPSUM

This is a surface mining operation employing 70 men and mining gypsum for use in the wall board industry.

Specimens were collected from dust settled near the primary crusher. Particle size ranges from 4 to 60 μm, the average being 15 μm. Dominantly gypsum with minor amounts of halite. Central stop dispersion shows tabular fragments of gypsum of index 1.520.

Observation under PH 400 show minor amounts of ascicular needles of "spar", a form of gypsum (<0.5%). Aspect ratio is less that 10:1 on these crystals and the minimum diameter observed was 2.5 μm.

5.8 CANADA WIDE MINES

The mine is temporarily shut down and its 200 operating crew laid off. The host rock is a layer of limestone and dolomite on a quartzite reef overlain by anhydrite. The lead and zinc minerals are located in the carbonates adjacent to the underlying quartzites.

Samples were collected both from the formations underground and from the crusher area.

Examination under central stop dispersion staining shows angular fragments of dolomite and gypsum in equal amounts, totalling 80% of the sample. The remainder is quartz with minor amounts of sphalerite and galina. Quartz occurs in a size range from 2 to 60 μm.

There are no fibrous components observable down to a resolution of 0.5 μm diameter.

5.9 CANADIAN ROCK SALT MINE - PUGWASH, NOVA SCOTIA

The underground rock formations consist of massive halite with layers of anhydrite interspersed. Occasional carnallite zones exist but are not extensive.

Examination of dust specimens from the crusher zone under dispersion staining and PLM reveal 80% halite, 20% anhydrite with minor carnallite, gypsum and calcite. Observed under phase contrast at 450X, the grain size has a mean value of 40 μm with a notable lack of free smaller components, which adhere to larger grains due to their hygroscopic nature.

There are no fibrous components visible in this ore.

Samples collected from the anhydrite-gypsum zones contain some "spar", an ascicular variety of gypsum. The smallest diameter observed was 50 μm.

5.10 NATIONAL GYPSUM, MELFORD, NOVA SCOTIA

The two level open pit operation of National Gypsum is the largest open pit gypsum operation in Canada, producing 10 - 20 thousand tons per day. Samples were collected both from the formations and the crusher area.

Examination of the crusher area settled dust reveals dominantly gypsum of a size range down to 1 μm and a mean of 12 μm. Ascicular crystals of "spar" are present but the smallest diameter observed was 5 μm. Minor amounts of fine grained clay minerals are present as a gypsum impurity but there is no evidence to suggest any fibrous component.

5.11 BAROID - BUCHANS

This is a barium reclaiming operation from the tailings of the Asarco mining. Since it is a wet operation, the product, when dried, is the only component likely to be contributing to air borne dust. Material collected at the site consists of 95% barite in a size range from sub-micron to 80 μm. The size distribution curve is flat and skewed so that 40% of the final produce (on a count basis) is within the respirable range. The remainder consists of gypsym, quartz, chlorite and the ore minerals of pyrhotite, spalerite and galena.

There are no fibrous minerals present in this produce down to a size range of 0.5 μm. Because of the source of the material, however, an XRF scan was run. Mercury and arsenic are absent but lead (2450 ppm) and Sr (7075 ppm) are present as well as trace amounts of Y, Zr, Nb, Le, V, Ce and Ga. If fibres are present in the sub micron range they could have access to many toxic heavy metals.

SUMMARY OF MINES INVESTIGATED

MINE	PRODUCT	FIBROUS MINERALS L/D > 3:1	FIBROUS MINERALS LD > 10:1	SILICA	PLATE MINERALS
N.B. MINING & SMELTING	Pb,Cu,Zn,Ag	Cleavage Frags	No	Yes	Yes
HEATH STEELE	Pb,Cu,Zn,Ag	Cleavage Frags	No	Yes	Yes
CONSOLIDATED DURHAM	Antimony	No	No	Yes	Yes
CONSOLIDATED RAMBLER	Copper	No	No	Yes	Yes
NFLD ZINC	Zinc	No	No	No	No
NFLD MINERALS	Pyrophyllite	Cleavage Frags	No	No	Yes
FLINTKOTE GYPSUM	Gypsum	Spar	No	No	No
CANADA WIDE MINES	Zinc	No	No	Yes	Yes
CANADIAN ROCK SALT	Halite	No	No	No	Yes
NATIONAL GYPSUM	Gypsum	No	No	No	Yes
BAROID	Barites	No	No	Yes	Yes

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